

## PERFORMING PASSIVE VOLTAGE CONTRAST ON A SILICON ON INSULATOR SEMICONDUCTOR DEVICE

### TECHNICAL FIELD

5 The present invention relates to the field of silicon on insulator (SOI) semiconductor devices, and more particularly to performing passive voltage contrast on a SOI semiconductor device.

### BACKGROUND INFORMATION

10 Semiconductor chips are used in many applications, including as integrated circuits and as flash memory for computing devices, wireless telephones, and digital cameras. Regardless of the application, it is desirable that a semiconductor chip hold as many circuits or memory cells as possible per unit area. In this way, the size, weight, and energy consumption of devices that use semiconductor chips advantageously is minimized, while nevertheless improving the memory capacity and computing power of the devices. Moreover, it is desirable that the devices operate at  
15 very fast speeds.

Among the things that can limit the speed with which semiconductor devices operate is extraneous capacitances in the devices. More specifically, undesired electrical capacitance can arise from the portions of the source and drain regions that overlap the gate region, as well as from the source and drain junctions. To limit  
20 junction depth and, hence, to decrease junction capacitance, so-called "silicon on insulator" ("SOI") technology, can be used in which a layer of oxide is buried in the silicon substrate to act as a stop to dopant diffusion (and, hence, to act as a stop to source/drain junction depth).

On top of this layer of oxide may reside a silicon region, commonly referred  
25 to as the "body." In the body, active regions, e.g., source and/or drain junctions, and

shallow trench isolation (STI) regions may be formed. On top of the body, a polysilicon gate may be separated from the body by a layer of gate oxide. However, if the gate oxide breaks down, a conductive path is formed between the gate and the channel or body. This may result in shifts in the threshold voltage from charge trapping thereby resulting in the defective operation of the SOI device.

One method for detecting defects, such as a gate oxide breakdown, is passive voltage contrast. In the passive voltage contrast technique, a scanning electron microscope (SEM) may direct electrons to an integrated circuit or wafer placed on a stage in a vacuum chamber. Upon directing electrons onto the test circuit or wafer, secondary electrons may be produced. These secondary electrons may be produced by interconnected structures. That is, secondary electrons may be produced when there is a conductive path for electrons to flow. The areas of a conductive path may be brighter than the areas in which there is not a conductive path based on the amount of secondary electrons produced. By determining if the area around the gate oxide region is dark or bright, a determination may be made as to whether there is a breakdown in the gate oxide region. If there is a breakdown in the gate oxide region, then the area will appear to be bright. The area will appear bright since a conductive path has been formed from the gate to the channel thereby resulting in secondary electrons being produced. If there is not a breakdown in the gate oxide region, then the area will appear dark.

However, the passive voltage contrast technique has not been able to be applied to detect breakdowns in the gate oxide regions in SOI semiconductor devices because SOI devices have included an insulator between the body and the substrate. This insulator prevents a conductive path forming from the gate to the substrate even when there is a breakdown in the gate oxide. Hence, the passive voltage contrast technique may indicate a dark area even when there is a breakdown in the gate oxide. Consequently, the passive voltage contrast technique cannot currently be performed on SOI semiconductor devices to detect a breakdown in the gate oxide. Similarly, the

passive voltage contrast technique cannot currently be preformed on SOI semiconductor devices to detect an open contact since closed contacts would appear to be open as the insulator in the SOI semiconductor device prevents a conductive path forming from the contact to the substrate.

- 5           Therefore, there is a need in the art to be able to perform passive voltage contrast on an SOI semiconductor device to detect a breakdown in the gate oxide as well as to detect open contacts.

**SUMMARY**

The problems outlined above may at least in part be solved in some embodiments by grinding and etching portions of the bulk substrate and box insulator of the silicon on insulator (SOI) semiconductor device, thereby allowing a conductive path to form between the gate and the substrate if there is a breakdown in the gate oxide. Further, a conductive path may also be formed between the contact and the substrate. Consequently, the passive voltage contrast technique may be applied to a SOI device to detect a breakdown in the gate oxide as well as to detect an open contact.

In one embodiment of the present invention, a method for performing passive voltage contrast on a silicon on insulator (SOI) device may comprise the step of grinding a first portion of a substrate of the SOI device with a dimpling tool. The method may further comprise etching a second portion of the substrate of the SOI device with tetramethyammonium hydroxide (TMAH) following the grinding of the SOI device with the dimpling tool. The method may further comprise etching a third portion of the substrate and a portion of a box insulator of the SOI device with hydrofluoric (HF) acid following the etching of the SOI device with TMAH. The method may further comprise applying a conductive coating to the etched portions of the substrate and the box insulator of the SOI device. Further, the conductive coating may be applied to a portion of a body of the SOI device. The method may further comprise directing a beam of electrons at the SOI device to detect a secondary emission from the SOI device.

The foregoing has outlined rather generally the features and technical advantages of one or more embodiments of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which may form the subject of the claims of the invention.

**BRIEF DESCRIPTION OF THE DRAWINGS**

A better understanding of the present invention can be obtained when the following detailed description is considered in conjunction with the following drawings, in which:

5           Figure 1 illustrates an embodiment of the present invention of a silicon on insulator (SOI) device;

          Figure 2 is a flowchart of a method for performing passive voltage contrast on the SOI device in accordance with an embodiment of the present invention;

10           Figure 3A illustrates an embodiment of the present invention of the SOI device after the step of grinding the substrate using a dimpling tool;

          Figure 3B illustrates an embodiment of the present invention of the SOI device after the step of etching the substrate using tetramethylammonium hydroxide (TMAH);

15           Figure 3C illustrates an embodiment of the present invention of the SOI device after the step of etching the substrate with TMAH and box insulator using hydrofluoric (HF) acid;

          Figure 3D illustrates an embodiment of the present invention of the SOI device after the step of applying a conductive layer using carbon ink; and

20           Figure 4 illustrates an embodiment of the present invention of a passive voltage contrast chamber used for detecting a breakdown in the gate oxide of the SOI device.

**DETAILED DESCRIPTION**

The present invention comprises a method and type of SOI device that enables performing passive voltage contrast on SOI devices. In one embodiment of the present invention, a first portion of a substrate of the SOI device may be ground with a dimpling tool. A second portion of the substrate of the SOI device may be etched  
5 using tetramethylammonium hydroxide (TMAH). A third portion of the substrate of the SOI device and a portion of a box insulator of the SOI device may be etched using hydrofluoric (HF) acid. By grinding and etching portions of the substrate and box insulator, a conductive path may now be formed by applying a conductive material shorting the transistor body to the SOI substrate. Consequently, the passive voltage  
10 contrast technique may be applied to the SOI device of the present invention to detect a breakdown in the gate oxide which would be illustrated by a bright area in the gate oxide region resulting from the secondary electrons produced. If there is not a breakdown in the gate oxide, then the gate oxide region will appear dark as there will not be a conductive path formed from the gate to the ground level of the SOI device.  
15 Further, the passive voltage contrast technique may be applied to the SOI device to detect an open contact which would be illustrated by a dark area around the defective contact region resulting from the lack of secondary electrons produced. If there is not an open contact, then the area around the contact region will appear bright as there  
20 will be a conductive path formed from the contact to the active area of the body of the SOI device.

It is noted that the present invention will be described in terms of certain semiconductor devices and certain structures within the semiconductor devices. However, the present invention is applicable to the testing of other semiconductor  
25 devices and/or additional or different structures. One of ordinary skill in the art will also readily recognize that for clarity, only certain portions of the semiconductor devices are depicted.

Figure 1- SOI Device

Figure 1 illustrates an embodiment of a semiconductor on insulator (SOI) semiconductor device 100 in accordance with the present invention. SOI device 100 may reside on bulk silicon 101 referred to as the "substrate." SOI device 100 may further comprise a layer of oxide 102, referred to as the "box insulator," residing on the bulk silicon 101. In one embodiment, oxide 102 may be composed of  $\text{SiO}_2$ . On top of box insulator 102 may reside a silicon region, referred to as the "body" 103. Body 103 may include active regions 104A-B, e.g., source/drain junctions, and shallow trench isolation (STI) regions 105A-B. Active regions 104A-B may collectively or individually be referred to as active regions 104 or active region 104, respectively. STI regions 105A-B may collectively or individually be referred to as STI regions 105 or STI region 105, respectively. Active regions 104A-B may be interconnected to metal-1 layer (not shown) via contacts 106A-B, respectively. Further, the top of SOI device 100 may be interconnected with a polysilicon gate 107 via contact 106C. Contacts 106A-C may collectively or individually be referred to as contacts 106 or contact 106, respectively. In one embodiment, contacts 106 may be comprised of tungsten. Polysilicon gate 107 may be separated from body 103 by a gate oxide 108. Contacts 106, polysilicon gate 107 and gate oxide 108 may be interposed by an interlayer dielectric 109. It is noted that SOI device 100 may comprise any number of contacts 106, active regions 104, STI regions 105, gates 107 and gate oxide regions 108, and that Figure 1 is illustrative.

As stated in the Background Information section, the passive voltage contrast technique has not been able to be applied to detect breakdowns in the gate oxide regions in SOI semiconductor devices because SOI devices have included an insulator between the body and the substrate. This insulator prevents a conductive path forming from the gate to the substrate even when there is a breakdown in the gate oxide. Hence, the passive voltage contrast technique may indicate a dark area even when there is a breakdown in the gate oxide. Consequently, the passive voltage

contrast technique has not been able to be performed on SOI semiconductor devices to detect either a breakdown in the gate oxide. Similarly, the passive voltage contrast technique has not been able to be performed on SOI semiconductor devices to detect an open contact as closed contacts would appear to be open as the insulator in the SOI semiconductor device has prevented a conductive path forming from the contact to the substrate. Therefore, there is a need in the art to be able to perform passive voltage contrast on an SOI semiconductor device to detect a breakdown in the gate oxide as well as to detect open contacts.

A method for performing passive voltage contrast on SOI device 100 to detect a breakdown in gate oxide 108 as well as to detect a contact 106 that is open is discussed below in conjunction with Figure 2. Figures 3A-D, as discussed further below in conjunction with Figure 2, illustrate embodiments of SOI device 100 after the steps of etching the substrate using a dimpler, etching the substrate using tetramethylammonium hydroxide (TMAH), etching the substrate and box insulator using hydrofluoric acid (HF) are performed, and applying carbon ink are performed, respectively. Figure 4, as discussed further below in conjunction with Figure 2, illustrates an embodiment of the present invention of a passive voltage contrast chamber used for detecting a breakdown in the gate oxide of the SOI device as well as for detecting a contact 106 that is open.

#### Figure 2 – Method for Performing Passive Voltage Contrast on a SOI device

Figure 2 is a flowchart of one embodiment of the present invention of a method 200 for performing passive voltage contrast on SOI device 100 (Figure 1).

Referring to Figure 2, in conjunction with Figure 1, in step 201, SOI device 100 is polished to metal-1 contact layers 106.

In step 202, a dummy integrated circuit is glued to the top surface of SOI device 100 to protect the top surface structures of SOI device 100 from inadvertent or

undesirable etching. The dummy integrated circuit may be glued to the top surface of SOI device 100 using a commercially available conventional epoxy.

5 In step 203, a first portion of substrate 101 is ground with a dimpling tool in the area below gate 107 as illustrated in Figure 3A. Referring to Figure 3A, Figure 3A illustrates an embodiment of the present invention of SOI device 100 where a portion of substrate 101 has been ground by a dimpling tool.

10 Returning to Figure 2, in conjunction with Figure 1, in step 204, a second portion of substrate 101 is etched with tetramethylammonium hydroxide (TMAH) in the area below gate 107 as illustrated in Figure 3B. Referring to Figure 3B, it illustrates an embodiment of the present invention of SOI device 100 where a second portion of substrate 101 has been etched by TMAH. The etching by TMAH should stop at box insulator 102 as TMAH does not etch oxide material.

15 Returning to Figure 2, in conjunction with Figure 1, in step 205, a third portion of substrate 101 and a portion of box insulator 102 are etched in the area below gate 107 using hydrofluoric (HF) acid. In one embodiment, the HF acid may etch box insulator 102 up to the border with body 103 but not including body 103 as illustrated in Figure 3C. Referring to Figure 3C, it illustrates an embodiment of the present invention of SOI device 100 where a third portion of substrate 101 and a portion of box insulator 102 has been etched by HF acid. Etching using HF acid may  
20 require careful attention as such etching for too long a time may cause an interaction with body 103.

Returning to Figure 2, in conjunction with Figure 1, in step 206, the dummy integrated circuit, that was glued to the top surface of SOI device 100 in step 202, is removed.

25 In step 207, a carbon ink coating is applied to the etched portions of silicon 101 and box insulator 102 as well as to a portion of body 103 in order to form a good

junction or ohmic contact with a sample holder or stage used in testing SOI device 100 with the passive voltage contrast technique as illustrated in Figure 3D. Referring to Figure 3D, it illustrates an embodiment of the present invention of SOI device 100 where a carbon ink coating 110 has been applied to the etch portions of substrate 101 and box insulator 102 as well as to a portion of body 103 in order to form a good  
5 junction or ohmic contact with a sample holder or stage used in testing SOI device 100 with the passive voltage contrast technique.

Returning to Figure 2, in conjunction with Figure 1, by etching portions of substrate 101 and box insulator 102 in steps 203-205, and applying a carbon ink  
10 coating layer 110 in step 207, a conductive path may now be formed from gate 107 to substrate 101 if there is a breakdown in gate oxide 108. Consequently, the passive voltage contrast technique, as discussed below, may be applied to SOI device 100 to detect a breakdown in gate oxide 108 which would be illustrated by a bright area resulting from the secondary electrons produced. If there is not a breakdown in gate  
15 oxide region 108, then the area surrounding gate oxide 108 will appear dark since there will not be a conductive path formed from gate 107 to ground level 110. Further, a conductive path may now be formed from contact 106 to substrate 101. The passive voltage contrast technique, as discussed below, may be applied to SOI device 100 to detect a contact 106 that is open which would be illustrated by a dark  
20 area around the defective contact region resulting from the lack of secondary electrons produced. If contact 106 is closed, then the area surrounding the contact region will appear bright since there will be a conductive path formed from the contact to the active area 104 of body 103 of SOI device 100.

In step 208, a beam of electrons is directed at SOI device 100 to detect a  
25 secondary emission from SOI device 100 during the testing of the device with the passive voltage contrast technique as illustrated in Figure 4. Referring to Figure 4, it illustrates an embodiment of the present invention of a passive voltage contrast chamber 300 used for detecting either a breakdown in gate oxide 108 of SOI device

100 or a contact 106 that is open. The passive voltage contrast technique may involve attaching SOI device 100 to a rotating stage 301 in vacuum chamber 300. Rotating stage 301 may include a support member 302 and a pivoting mechanism 303. Once SOI device 100 on stage 301 has been rotated into the appropriate location to test the area surrounding gate oxide 108, a scanning electron microscope (SEM) 304 may  
5 direct electrons to the gate oxide 108 area on SOI device 100 or to the region surrounding a contact 106. A detector 305 may be configured to detect any secondary electrons that may be produced by interconnected structures. That is, secondary electrons may be produced when there is a conductive path for electrons to  
10 flow. The areas of a conductive path may be brighter than the areas in which there is not a conductive path based on the amount of secondary electrons produced. Hence, by determining if the gate oxide region 108 is dark or bright, a determination may be made as to whether there is a breakdown in gate oxide region 108. If there is a breakdown in gate oxide region 108, then the gate oxide region 108 will appear to be  
15 bright. The area will appear bright since a conductive path has been formed from gate 107 to ground level 110 thereby resulting in secondary electrons being produced. If there is not a breakdown in gate oxide region 108, then the gate oxide region 108 will appear dark. Further, by determining if the area surrounding a contact 106 is dark or bright, a determination may be made as to whether contact 106 is open or  
20 closed. If contact 106 is closed, then the area will appear to be bright. The area will appear bright since a conductive path has been formed from contact 106 to active area 104 of body 103, thereby resulting in secondary electrons being produced. If contact 106 is open, then the area will appear dark around the defective contact due to the lack of secondary electrons being produced.

25 It is noted that one of ordinary skill in the art will readily recognize that method 200 may include other and/or additional steps that, for clarity, are not depicted. It is further noted that method 200 may be executed in a different order presented and that the order presented in the discussion of Figure 2 is illustrative. It

is further noted that certain steps in method 200, e.g., 202, and 206, are not necessary to be executed in order to perform the passive voltage contrast technique on SOI semiconductor device 100. Steps 202 and 206 may not be necessary if there is not a concern of protecting the top surface structures of SOI device 100 from inadvertent or undesirable etching.

Although the method and SOI device are described in connection with several embodiments, it is not intended to be limited to the specific forms set forth herein, but on the contrary, it is intended to cover such alternatives, modifications and equivalents, as can be reasonably included within the spirit and scope of the invention as defined by the appended claims. It is noted that the headings are used only for organizational purposes and not meant to limit the scope of the description or claims.